

Radio Properties of NLS1s

Edward C. Moran

Department of Astronomy, University of California, Berkeley, CA 94720 USA

While NLS1s have been studied intensively at X-ray and optical wavelengths, comparatively little is known about their characteristics in the radio band. Therefore, we have carried out an investigation of the radio luminosities, source sizes, spectral index distribution, and variability of a large, uniformly selected sample of NLS1s. Our results indicate that, in some respects, the radio properties of NLS1s differ significantly from those of classical Seyfert galaxies. Radio observations of NLS1s may thus provide important clues regarding the nature of their nuclear activity.

1 Introduction

It is well established that the optical and X-ray characteristics of narrow-line Seyfert 1 galaxies distinguish them from all other types of active galactic nuclei (AGNs). Unfortunately, the radio properties of NLS1s have been less well explored. In the only study dedicated to the subject, Ulvestad, Antonucci, & Goodrich (1995; hereafter UAG) found that NLS1s do not differ noticeably from nearby classical type 1 and type 2 Seyfert galaxies at centimeter wavelengths, in contrast to the results obtained in the optical and X-ray bands. This conclusion was based on the modest radio powers (10^{20} – 10^{23} W Hz $^{-1}$) and small radio source sizes ($\lesssim 300$ pc) of the objects they examined. But as UAG candidly noted, their sample of NLS1s was not defined using a uniform set of criteria, and only a fraction of the galaxies in it (9/15) was detected. We have investigated the radio emission of a larger, uniformly selected sample of NLS1s in order to gain further insight into the radio nature of these objects and their relation to other classes of AGNs.

Our sample of 24 NLS1s is drawn from the catalog of *IRAS* sources detected in the *ROSAT* All-Sky Survey (Boller et al. 1992; Moran et al. 1996). Full details regarding the sample definition are provided in Moran et al. (2000). We have obtained simultaneous high-resolution A-array VLA observations at 20 cm and 3.6 cm of most of the *IRAS*- and *ROSAT*-Observed NLS1 (“IRON”) galaxies. In addition, nearly all of the objects have been imaged at 20 cm in

the moderate-resolution B and C arrays by Condon et al. (1998a) and in the low-resolution D array as part of the NRAO VLA Sky Survey (Condon et al. 1998b). All but one of the IRON galaxies are detected at 20 cm; 22 have three or more flux density measurements at that wavelength.

2 Population Statistics

Radio Power Distribution. As Figure 1a illustrates, the majority of the IRON objects have radio powers in excess of $10^{23} \text{ W Hz}^{-1}$, and seven are more luminous than $10^{24} \text{ W Hz}^{-1}$ —in stark contrast to the 20 cm radio power distribution for nearby classical Seyfert galaxies (Ulvestad & Wilson 1989). Thus, it would appear that NLS1s are frequently more luminous than nearby Seyferts in the radio band. We have also determined the 20 cm luminosity distribution for 77 classical Seyfert galaxies in the *IRAS-ROSAT* catalog from which the IRON sample was drawn, based on VLA observations by Condon et al. (1998a). As indicated in Figure 1b, the radio luminosities of the IR/X-ray-selected Seyferts tend to be higher than those of the nearest classical Seyfert galaxies, but they do not extend to the very high luminosities displayed by NLS1s selected the same way. Interestingly, the radio-to-infrared and radio-to-X-ray flux ratio distributions of the IRON galaxies and the *IRAS-ROSAT* Seyferts do *not* differ significantly, suggesting that the IRON galaxies have higher 20 cm radio powers because they are more luminous sources at several wavelengths, not because their radio emission is enhanced in some way.

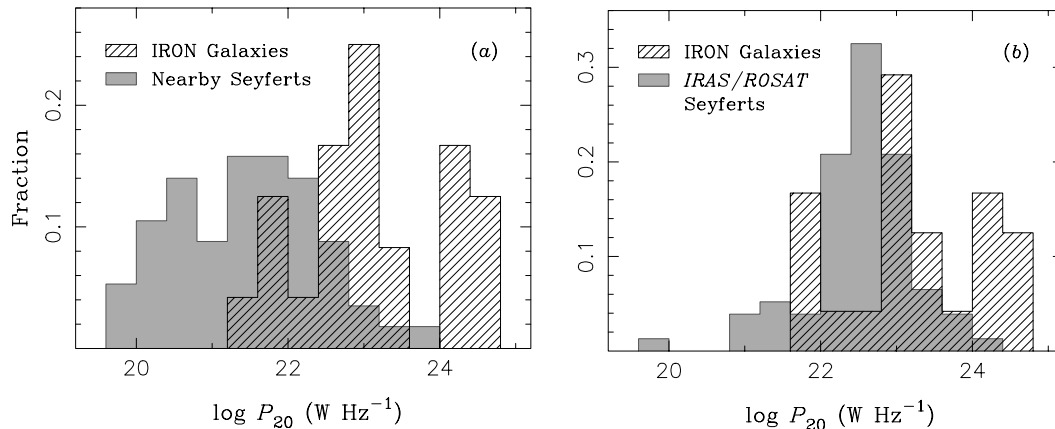


Fig. 1. Rest-frame 20 cm radio luminosity distribution for the IRON sample, compared to the radio luminosities of (a) nearby classical Seyfert galaxies (Ulvestad & Wilson 1989) and (b) classical Seyfert galaxies in the *IRAS-ROSAT* sample (Moran et al. 1996; Condon et al. 1998a).

Radio Source Sizes. Most of the IRON galaxies are unresolved at $\sim 1''$ resolution, confirming the conclusions of UAG that the nuclear radio sources in

NLS1s are compact. However, in our 3.6 cm observations ($0''.25$ resolution), two sources (IRAS 06269–0543 and Ark 564) exhibit an unresolved core and what appears to be a small-scale ($\sim 1''$) jet (Fig. 2).

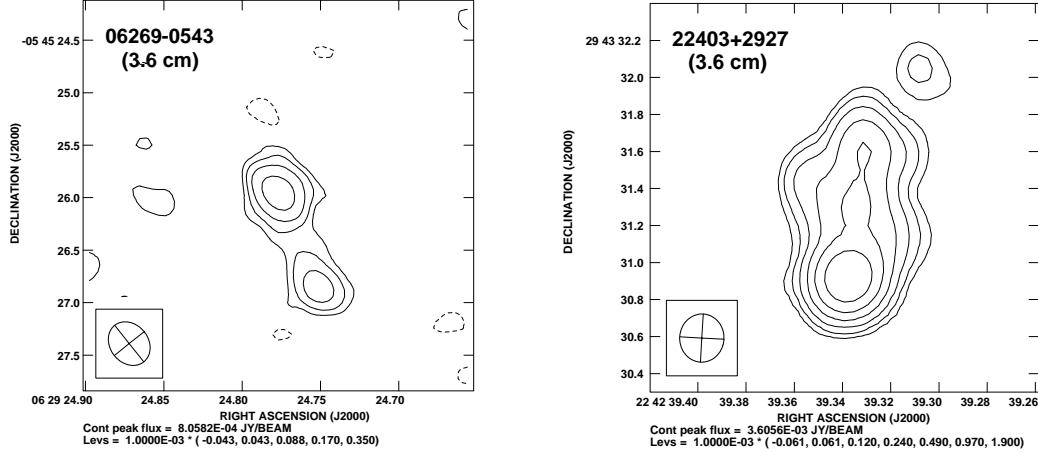


Fig. 2. VLA A-array images of two *IRAS-ROSAT* NLS1s with evidence for extended radio emission. IRAS 22403+2927 is better known as Ark 564.

Spectral Index Distribution. In Figure 3 we have plotted the radio spectral index distribution for the IRON galaxies; also shown is the distribution of spectral slopes for 59 of the classical Seyfert galaxies in the distance-limited sample of Morganti et al. (1999). Clearly, the IRON galaxies tend to have significantly steeper radio spectra than the classical Seyferts. Only one of the IRON objects has a spectrum flatter than $\alpha = 0.4$, and the bulk of the objects have $\alpha \approx 1.1 - 1.2$, well out on the tail of the Morganti et al. Seyfert distribution. One remarkable source, IRAS 06269–0543, has a spectral index of $\alpha = 2.21$, which is steeper by far than the spectrum of any core-dominated Seyfert galaxy or radio-quiet quasar we are aware of.

Variability. It is difficult to evaluate the radio variability of the IRON sample because of resolution effects associated with the different VLA configurations used for the 20 cm observations. However, a few galaxies exhibit flux density differences that are not instrumental in nature, including IRAS 06269–0543 (38% variability) and IRAS 20181–2244 (18% variability).

3 Implications for the Physical Nature of NLS1s

The nuclear radio sources in the IRON galaxies tend to be compact, steep-spectrum, and, in a few cases, variable—three characteristics that are rarely found together. This unusual combination of properties can be accounted for if most of the radio flux arises from a tiny (~ 1 pc diameter) region near the central engine of the active nucleus. In this scenario, the variability is not

intrinsic to the source, but is caused by “scintillation” as the emission passes through the interstellar medium of the Milky Way (e.g., Rickett 1990). Due to the proximity of the radio-emitting plasma to the intense optical/UV continuum source, the cooling of the electrons is dominated by inverse-Compton scattering rather than synchrotron emission, which steepens the radio spectrum. In the case of IRAS 06269–0543, our calculations indicate that the electron cooling time would be very short in this picture, suggesting that relativistic electrons are being continuously resupplied. This might occur if the mass accretion rate in this object is very high relative to the Eddington limit, which has been suggested to explain the steep soft X-ray spectra and rapid, large-amplitude X-ray variability observed in some NLS1s (Pounds et al. 1995; Boller et al. 1996). A thorough description of this hypothesis, which can be tested with additional radio observations, is provided in Moran et al. (2000).

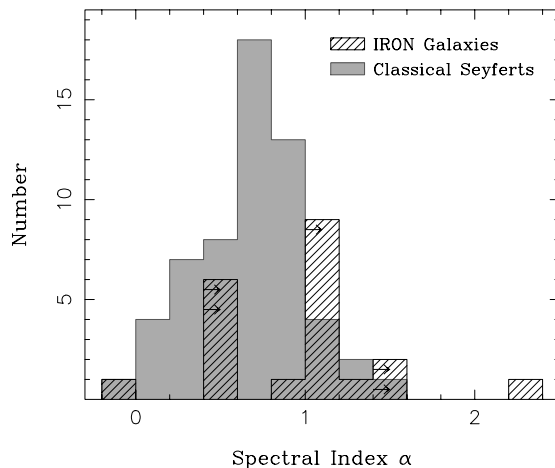


Fig. 3. Radio spectral index distributions (assuming $S_\nu \propto \nu^{-\alpha}$) for the IRON galaxies and 59 of the classical type 1 and type 2 Seyfert galaxies in the distance-limited sample of Morganti et al. (1999).

References

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